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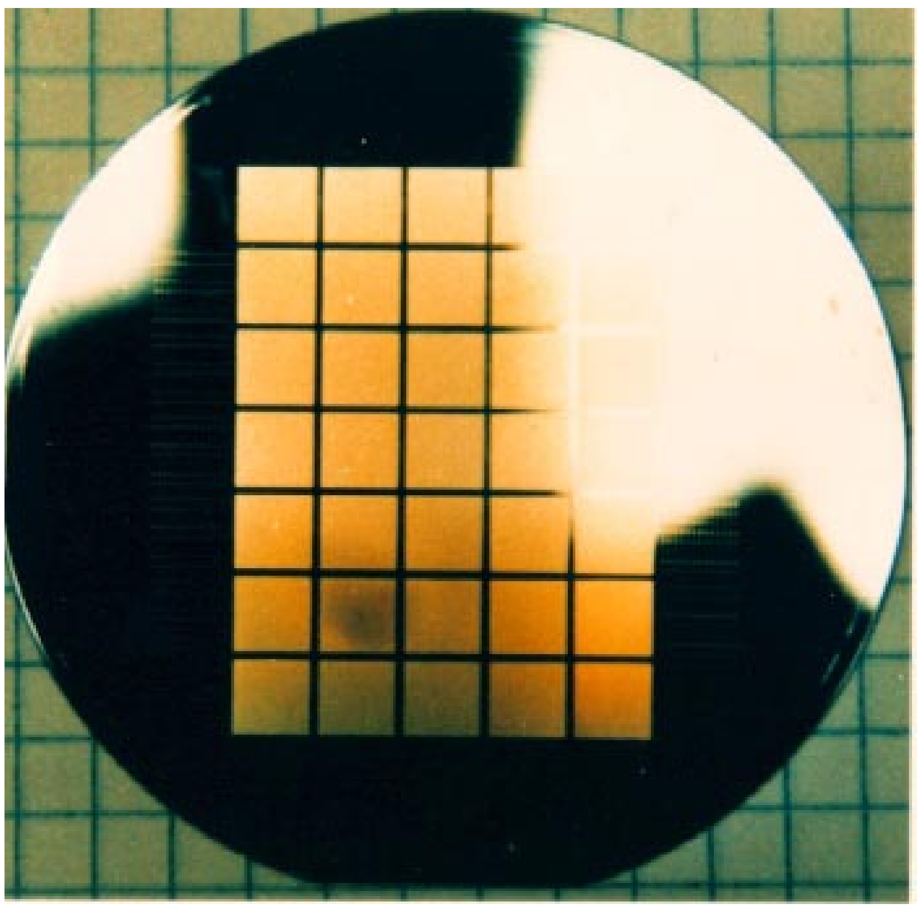
Center for Space Microelectronics Technology

1993 Technical Report



February 28, 1995

ON THE COVER: Thirty-five 128 x 128 quantum-well infrared photodetector (QWIP) arrays on a three-inch GaAs wafer. This focal plane array could be used for space-based imaging at 15 micrometers. Exceptionally rapid progress has been made in the development of very long wavelength QWIP focal plane arrays since they were first experimentally demonstrated only a few years ago.

The research described in this publication was carried out by the Jet Propulsion Laboratory, California Institute of Technology, and was sponsored by the National Aeronautics and Space Administration, Ballistic Missile Defense Organization/ Innovative Science and Technology Office, Advanced Research Projects Agency, U. S. Army, U. S. Navy, U. S. Air Force, and U. S. Department of Energy.

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Abstract

The 1993 Technical Report of the Jet Propulsion Laboratory Center for Space Microelectronics Technology summarizes the technical accomplishments, publications, presentations, and patents of the Center during the past year. The report lists 170 publications, 193 presentations, and 84 New Technology Reports and patents.

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Director's Report

The Center for Space Microelectronics Technology (CSMT) was founded in 1987 at the Jet Propulsion Laboratory (JPL) of the California Institute of Technology (Caltech). NASA and several Department of Defense agencies with space responsibilities established CSMT in order to create a critical mass program in space microelectronics with world-class facilities, equipment, and staff.

The Center concentrates on innovative high-risk, high-payoff concepts and devices with the potential to enable future space missions and to significantly enhance current and planned missions. CSMT conducts research and development in four technical areas: solid-state devices, photonics, custom microcircuits, and advanced computing. Research and development is pursued through proof-of-concept demonstrations, and successes are transferred to engineering development for government mission applications and to industry for commercialization.

The CSMT focuses on aspects of microelectronics and advanced computing that are unique to space applications. These areas include sensors for those portions of the electromagnetic spectrum inaccessible from Earth because the atmosphere is opaque; microinstruments and microelectronic systems for miniature spacecraft, and high-performance computing both in space and on the ground for mission data analysis and visualization.

The Center’s technical program continues to be intellectually and fiscally healthy. The program is focused on “customer” needs, which continue to evolve as NASA moves toward smaller, more frequent missions and the Department of Defense emphasizes tactical and theater-based systems. Fortunately, the Center’s long-range thrust into high-risk/high-payoff research and development (e.g., microsensors and microinstruments, innovative detectors, miniature electronics and micro-electromechanical systems or MEMS) matches these sponsor trends and offers innovative solutions to emerging sponsor needs.

Many CSMT technologies have commercial as well as government mission applications. The U.S. Department of Commerce joined CSMT in 1991 and urged the Center and its sponsors to emphasize commercial applications with the potential to aid U.S. industry's technological competitiveness. This "head start" allowed the Center to initiate programs with a strong emphasis on dual-use technologies and partnerships with U.S. industry. During the last year, the Center has entered into 15 cooperative agreements with U.S. industry, in the areas of electronics, computing, communications, automotive, and health care. These collaborations are with large and small businesses, as well as small-disadvantaged and woman-owned companies.

Policy guidance and program oversight for the Center are provided by the CSMT Board of Governors. Board members include major sponsors of the Center, the Director of JPL, and the Caltech President and Provost.

The members of the CSMT Board of Governors are:

- ❑ Dr. Edward Stone, Director of JPL, Chairman
- ❑ Dr. Gary Denman, Director of the Advanced Research Projects Agency
- ❑ Dr. Dwight Duston, Director of the Ballistic Missile Defense Organization (BMDO)/Innovative Science and Technology Office
- ❑ Dr. Thomas Everhart, President of Caltech
- ❑ Dr. Wesley Huntress, Associate Administrator of NASA/ Office of Space Science
- ❑ Dr. Martha Krebs, Director of the Office of Energy Research, Department of Energy
- ❑ Dr. Paul Jennings, Vice President and Provost of Caltech
- ❑ Dr. John Mansfield, Associate Administrator, NASA Office of Space Access and Technology
- ❑ Dr. Mary Good, Undersecretary for Technology, Department of Commerce

Seven world-renowned scientists, who comprise the CSMT Scientific Advisory Board, review the technical program and provide advice to the Board of Governors and CSMT Director. The Scientific Advisory Board's report is found later in this issue.

The remainder of this Director's Report summarizes the last year's achievements on the technical, programmatic, and institutional fronts.

TECHNICAL HIGHLIGHTS

Key accomplishments of CSMT scientists and engineers during the past year are as follows:

- ❑ Rapid prototyping of new ideas, in which a project quickly develops a concept into a demonstration, such as:
  - Ultraviolet charge-coupled device (CCD) imager using an MBE-deposited delta-doped layer
  - Space radiation effects monitor
  - Real-time path planning neural network chip
  - Hot electron bolometer mixer at 600 GHz
  - Tunneling microaccelerometer
  - Tunneling infrared sensor (micro-Golay cell)
  - Ultra-high-frequency capacitive microseismometer
  - Micromachined pressure, temperature, wind, and humidity sensors
  - Extractor for neural network-based digital map features
  - Real-time three-dimensional visualization software on parallel computers
  - Scalable synthetic aperture radar (SAR) processing software on parallel computers
- ❑ Participation by CSMT scientists in numerous technology demonstrations and validation experiments, including:
  - **Radiation and Reliability Assurance Experiment (RRELAX/ Clementine).** This JPL experiment, characterizing the radiation resistance and reliability of complementary metal-oxide semiconductors (CMOS) CCDs, static random access memory (SRAM) and radiation monitor (RADMON) devices, was launched on the Ballistic Missile Defense Organization (BMDO) Clementine spacecraft in January 1994
  - **3-D Neural Network Interceptor Technology.** The end product was a three-dimensional neural net software, delivered to Irvine Sensors for BMDO's Interceptor/Fast Frame Seeker Application.

- **High-Temperature Superconductor Space Experiment.** A joint NASA Lewis Research Center (LeRC)/JPL experiment to demonstrate a low-noise receiver subsystem using high-temperature superconductors was delivered to the Naval Research Laboratory for its scheduled launch in September 1995.

- **Space Technology Research Vehicle (STRV).** Three CSMT technology experiments were flown on the BMDO's STRV 1b spacecraft.

- **Kuyper Airborne Observatory (KAO).** Superconducting mixers fabricated in the JPL Microdevices Laboratory were able to detect the $H_2{}^{18}O$ ground-state line at 547 GHz in two molecular clouds (OMC-1 and SgrB2).

- **Caltech Submillimeter Observatory (CSO).** CSMT successfully implemented the superconducting–insulator–superconducting (SIS) junction 640-GHz receiver for planetary and astrophysical observations. HCl was observed for the first time in several sources including: IRC 10216 (star), monocerous R2 (supernova remnant), Jupiter (tentative detection in upper atmosphere), and Orion Molecular Cloud ($H^{35}Cl/H^{37}Cl$ ratio).

❑ Among its technical achievements, CSMT scientists and engineers accomplished the following:

- **Electron Tunneling Accelerometer.** One-axis, 1-gram, 10^{-7} g accelerometers have been operational for more than 12 months. A single-axis prototype hydrophone was delivered to the Naval Air Warfare Center (NAWC) for calibrator tank testing and demonstrated an order-of-magnitude improvement in performance over existing accelerometers of similar size and mass. For similar performance, mass was reduced 10 to 100 times.

- **Electron Tunneling Infrared Sensor.** Operational prototypes of infrared sensors and raw transducers were delivered to the University of Michigan, Stanford, University of California–Los Angeles (UCLA), NAWC, Eaton Corp., Caltech, and Altadena Instruments. This included the design, fabrication, and operation of a 1-by-4 line array. Sensitivity characterization is in progress.

- **Advanced LIGA for X-Ray Collimators.** LIGA is a German acronym signifying a combination of deep-etch x-ray lithography, electroplating, and injection molding. The technique requires a substantial infrastructure, including a synchrotron radiation source such as those found at Stanford and University of California (U.C.) Berkeley. A collaboration to rapidly develop the LIGA technique was formed between JPL, the Lawrence Berkeley Laboratory, Sandia California Laboratory, the Lawrence Livermore National Laboratory, U.C. Berkeley, and Stanford University, as well as several industrial partners. The primary focus of the JPL team is fabrication of fine-modulation collimators to enable downsizing of the proposed high-energy solar-imaging (HESI) satellite.

- **GaAs Quantum Well Infrared Photodetectors (QWIP)**. A demonstration of 15-μm QWIPs met the Atmospheric Infrared Sounder (AIRS) D* requirement of 52 K by optimizing the detector structure, random reflector, and materials growth. Several prototype AIRS focal plane arrays (FPAs) were fabricated; fabrication and characterization of 128-by-128 QWIP FPAs with random reflectors was completed—the first ever demonstration of such FPAs operating at the 15-μm wavelength.

- **Delta-Doped CCD for Enhanced Ultraviolet Response.** Delta-doped CCDs up to 1024-by-1024 pixels were fabricated. The devices show 100-percent internal quantum efficiency down to 121 nm, excellent lateral uniformity, and QE stability on the time scale of years. With the addition of antireflective coatings, efficiencies as high as 90 percent were obtained.

- **High-Speed Devices**. Schottky-collector resonant tunneling diodes were fabricated on InGaAs/AlAs material with a maximum oscillation frequency of approximately 2.2 THz—far higher than the previous record. In addition, high-electron-mobility transistor (HEMT) circuits for grid amplifiers that incorporate new gate-biasing networks were fabricated and delivered, and rectifier diodes for converting microwave power to direct current are being fabricated for the Microwave-Powered Aircraft Platform System (MAPS) project.

- **Submillimeter Sensors.** The state-of-the-art has been advanced from 200 to 750 GHz for the SIS receiver. Performance has been improved to less than 10 hn/k, achieving the sensitivity needs of the Submillimeter Intermediate Mission/Far Infrared Space Telescope (SMIM/FIRST) from 400 to 700 GHz.

- **Active Pixel Sensors (APS).** Demonstrations included a 128-by-128 CMOS APS with on-chip timing, control, and signal chain circuits and a 256-by-256 CMOS APS detector array and camera. CMOS APS technology was successfully transferred to AT&T Bell Laboratories.

- **High-Temperature Superconductors.** YBaCuO junctions on silicon-on-sapphire were demonstrated, enabling integration with semiconductor circuits. A low-noise 7.4-GHz frequency downconverter has been delivered for a September 1995 launch. JPL and Honeywell have demonstrated high-detectivity YBaCuO infrared bolometers.

- **Optical Neocognitron.** A 225-channel optical wavelet processor breadboard for missile, cancer cell, and car license plate detection was built and demonstrated. Both e-beam multiple-phase and liquid-crystal wavelet filters (updatable at 30 frames/s) were fabricated.

- **Vertical Bloch Line Storage.** Vertical bloch line solid-state and nonvolatile data-storage chips at 25 Mbits/cm^2 were designed, simulated, and tested. The input/output data line, responsible for moving data between external chip interfaces and the internal VBL storage area, was successfully operated between DC and 1.66 MHz. An output signal level of 5 microvolts per micrometer of detector length per milliampere of sense current was generated, corresponding to a pre-sense-amplifier signal level of 3.75 millivolts.

- **Neural Networks.** An ultra-high-speed analog neurosynapse custom-VLSI chip that performs pattern recognition in less than 150 ns was demonstrated. A neural net chip with in-situ learning capability was flown on a joint U.S.–United Kingdom Space Technology Research Vehicle (STRV-1b) in geotransfer orbit. The chip's radiation tolerance was also validated by extensive ground radiation studies.

PROGRAMMATIC HIGHLIGHTS

❑ CSMT hosted or sponsored the following technical workshops during 1993:

- Fourth and Fifth Ballistic Electron Emission Microscopy Workshop held in Williamsburg, Virginia, on January 25, 1993 and in Mohawk, New York, on January 24, 1994.

- Ballistic Missile Defense Organization Critical Design Review for Clementine Radiation Experiments held in Pasadena, California, on January 20, 1993.

- The Second CSCC Delta Applications Workshop held in Pasadena, California, on March 25 and 26, 1993.

- Fourth International Conference on Space Terahertz Technology—Joint with University of Michigan and University of California, Los Angeles, on March 30–April 1, 1993

- Workshop on Innovative Concepts for Mars Environmental Survey (MESUR) Network Micro-Lander held in Arcadia, California, on April 5–6, 1993.

- 1993 IEEE Workshop on Charge-Coupled Devices and Advanced Image Sensors, held in Waterloo, Canada, on June 9–12 , 1993.

❑ CSMT personnel served on numerous panels and committees, including many technical conference organizing and program committees, as well as the following:

- Executive Committee of the American Physical Society

- Executive Board and General Council of the American Physical Society

- Air Force Scientific Advisory Board

- Sensor Technology Committee of the American Institute of Aeronautics and Astronautics

- Lillienfeld and Isaakson Prize Committees of the American Physical Society

- Fellowship Nomination Committee of the Laser Science Focus Group of the American Physical Society

- Intercenter Microspacecraft Technology Program Planning Team

- Joint Services Electronics Program, Technical Review Committee

- Technical Representative Committee, NASA–University of Michigan Center for Space Terahertz Technology

- Concurrent Supercomputing Consortium Policy Board

- Space Technology Interdependency Group (STIG)

- NASA Sensor Working Group
- Defense Intelligence Agency, National MASINT Architecture Steering Committee
- NASA High-Performance Computing and Communications Program, executive and technical committees
- National Science Foundation Program Advisory Panel for Advanced Scientific Computing
- Information Systems Management Committee, NASA Office of Space Science
- Institute of Electrical and Electronic Engineers (IEEE), Technical Advisory Committee on Parallel Processing
- Department of Energy (DOE), Energy Research Supercomputing Users' Group Executive Committee
- Army High-Performance Computing, Research Center Advisory Committee
- Advisory Panel for Scientific Computing Division, National Center for Atmospheric Research
- Committee on Science Policy of the Society for Industrial and Applied Mathematics
- Los Alamos Computing and Communication Division Advisory Committee
- American Vacuum Society, Nanometer and Technology Division
- Surface Science Spectra Executive Committee
- International Standards Organization (ISO), Technology Advisory Group on Surface Chemistry
- American Vacuum Society, Chair of the Southern California Chapter
- American Vacuum Society, Chair of the Electronics Materials and Processing Division and numerous technical conference organizing and program committees

- A number of awards were presented to CSMT scientists and engineers. Most notable were the following:

  - Two of four JPL **Lew Allen Awards** were presented to CSMT staff:

    - **Pierre Baldi**, in recognition of his scientific contributions to the theory and applications of artificial neural systems.

    - **Seth Marder**, for contributions to the science of organic materials for nonlinear optics and for his efforts to disseminate the results of his work to the community and to motivate and train students in the art of conducting research.

  - **NASA Medals** were awarded to the following CSMT staff members:

    - **H. G. Leduc** — Exceptional Scientific Achievement

    - **Edward T. Chow** — Exceptional Engineering Achievement

  - **1993 "R&D 100" Award**

    - **Tom Kenny, William Kaiser, Judi Podosek**, and **Erika Vote** received "R&D 100" Awards for the uncooled infrared tunnel sensor, as one of the 100 most technologically significant new products of the year. This award is sponsored by *R&D Magazine*.

- CSMT again hosted several Distinguished Visiting Scientists. Participants were:

  - **Dr. Junichi Nakamura,**
    Olympus America

  - **Dr. Anne Bagneres**
    Department of Electrical Engineering,
    Boston University

  - **Dr. Floyd Humphrey**
    Department of Electrical Engineering,
    Boston University

  - **Prof. Linda Katehi**
    Electrical Engineering,
    University of Michigan

- **Dr. Venkatesh Narayanamurti**
  College of Engineering
  University of California at Santa Barbara

- **Dr. Antti V. Raisanen**
  Senior Research Fellow, National Research Council
  Helsinki University of Technology, Espoo, Finland

- **Dr. Dimitris Pavlidis**
  NASA Center for Terahertz Technology,
  University of Michigan

- **Prof. Michael G. Spencer**
  Department of Physics,
  Howard University

- **Dr. Pochi Yeh**
  Department of Electrical and Computer Engineering,
  University of California at Santa Barbara

INSTITUTIONAL HIGHLIGHTS

❑ Pursuit of dual-use cooperative technology development programs with U.S. industry has continued to be a strong focus for CSMT over the past year. Some highlights of our activities are detailed below:

- **Technology Cooperative Agreements (TCA).** CSMT has entered into TCAs with 15 American companies for joint development of technologies with both NASA and commercial applications. The technologies include sensors, neural networks, onboard computing, and high-performance computing. The companies represent aerospace, electronics, computer, automotive, health care, and other industry segments, including small disadvantaged businesses.

- **Small Business Technology Transfer (STTR) Program.** The STTR was established last year with the explicit objective of transferring technology from government laboratories to small businesses. Two small companies were awarded STTR funds to obtain technologies from CSMT.

- **Visiting Industrial Fellowship Program.** During its first year, this new program brought six visitors from industry to JPL to acquaint them with our programs in order to facilitate technology transfer.

I. Solid-State Devices

OVERVIEW

The Solid-State Device Research Program is directed toward developing innovative devices for space remote and in situ sensing, and for data processing. Innovative devices can result from “standard” structures in innovative materials, such as low- and high-temperature superconductors or strained-layer superlattices, or from “innovative” structures achieved using electron tunneling or nanolithography in standard materials. A final step is to use both innovative structures and innovative materials. A new area of emphasis is the miniaturization of sensors and instruments using the techniques of electronic device fabrication to micromachine silicon into micromechanical and electromechanical sensors and actuators.

1993 MAJOR TECHNICAL ACHIEVEMENTS

❑ **Electron Tunneling**

- **Observed** "reverse" temperature dependence of carrier transport. These observations were the first energy-resolved, wide-range measurements of carrier transport in semiconductor heterostructures. The technology has applications in heterostructure bipolar devices and quantum well infrared photodetectors (QWIPs).

- **Discovered** important heterogeneity in SiGe strained systems. First experimental measurement of SiGe conduction band splitting. These findings will find applications in heterostructure bipolar devices, two DEG high-mobility structures.

- Directly **measured** band structure of AIAs conduction band. First measurement of band. Complete characterization of AIAs tunnel barriers. Applications: heterostructure devices, QWIP infrared detectors, and resonant tunneling devices.

- **Fabricated** new tunneling transmission microscopy (TTM) instrument. Characterized transport and high-bias tunneling properties of thin-film structures.

- **Supported** technology transfer of ballistic electron emission microscopy (BEEM) to surface/interface. Selected as a highlight by the National Technology Transfer Center, supported by the BMDO. Planned new technology transfer activities.

- **Applied** TTM instruments to new technology transfer program in flat panel display development; one of the most important strategic U. S. technologies.

- **Modified** tunneling infrared sensor to improve noise equivalent power (NEP) to 3 x 10^{-10} W/√Hz. Modifications include development of improved absorber, placement of absorber on suspended structure inside cell, and optimization of pinhole fabrication technique.

- Successfully **demonstrated** a dual-element tunneling accelerometer. Live demonstration for sponsor was completed in March 1993. First accelerometer packaged for underwater testing scheduled for delivery in January 1994.

- **Designed**, **fabricated, and operated** first membrane-based tunneling magnetometer.

- **Delivered** membrane-based tunneling magnetometer to Eaton Corporation, where it was successfully evaluated.

- **Designed**, **fabricated, and delivered** torsional magnetometer components to Naval Research Laboratory (NRL) for assembly and testing. Successful operation reported by NRL.

- **Demonstrated** the tunneling infrared sensor without failure for one year; it has operated continuously in the JPL Microdevices Laboratory.

- **Initiated** low-noise/low-temperature testing of tunneling transducers in Professor Michael Roukes' group at Caltech.

- **Delivered** sensors this year to Eaton Corporation, Altadena Instruments, NRL, NAWC, Caltech, and UCLA.

❑ Superconductivity

- **Delivered** a prototype low-noise receiver subsystem to the Naval Research Laboratory for testing of the High-Temperature Superconductor Space Experiment Phase II (HTSSE-II), in collaboration with JPL Section 336. Section 346's contribution was the high-temperature superconductor (HTS) bandpass filters for incorporation on the input end of the receiver. Microwave tests of the receiver subsystem show significantly lower noise temperatures than a receiver using cooled normal metal components. The HTSSE-II project is a collaboration between JPL and the NASA Lewis Research Center (LeRC). The scheduled launch date is November 1995.

- **Delivered** HTS bandpass filters for incorporation into a low-noise receiver for the HTSSE-II qualification and flight units. Tests of five of the filters show that the HTS filters perform significantly better than Cu filters at the operating temperature of 77 K ±1 K, with a transmission loss of 0.3 dB at the operating frequency of 7.4 GHz, compared to 0.8 dB for the Cu filter. Four of the filters maintained better performance than the Cu filter at temperatures up to 89 K.

- **Delivered** HTS oscillator circuits to NASA LeRC for the HTSSE-II qualification and flight units. These circuits were originally to be fabricated by LeRC, but delivery was not possible due to problems with HTS film quality and/or device processing. Since this deliverable was already a month late, the decision was made to grow the HTS films and fabricate the devices at JPL. Successful delivery of circuits for the qualification unit was made in five days (October). Tests at NASA LeRC show the JPL-fabricated circuits to be of high quality. Subsequently, three circuits for the flight unit were delivered in November 1993.

- **Delivered** for testing YBaCuO microwave bandpass filters for use in a prototype receiver for the Deep Space Network.

- **Delivered** YBaCuO epitaxial thin films on 3-inch Si substrates to Honeywell for bolometer process testing. The YBaCuO film thickness varied by 40 percent, and the superconducting transition temperature was greater than 80 K over most of the wafer. These results are adequate for prototype bolometer array fabrication.

- **Demonstrated** the first-time growth of (100) oriented CeO_2 on a Si (100) substrate utilizing a cubic-zirconia buffer layer. CeO_2 may serve as an improved buffer layer for YBaCuO growth on Si.

- **Demonstrated** the growth of (100) oriented BaF_2 on Si (100) substrates, using yttria-stabilized zirconia (YSZ) and CeO_2 buffer layers. BaF_2 is of interest because of its low dielectric constant, plastic deformability, and chemical compatibility with YBaCuO. These films may be useful in high frequency applications and as a buffer layer for thick YBaCuO layers on Si, which crack on the usual YSZ buffer layer because of the mismatch in thermal expansion coefficients. A YBaCuO film with T_c = 88 K has been grown on a $BaF_2/CeO_2/YSZ/Si$ (100) structure.

- **Developed** a novel multilayer buffer system which enables the growth of very high quality $YBa_2Cu_3O_{7-x}$ (YBCO) thin films on silicon-on-sapphire (SOS) substrates. This capability provides the basis for superconductor/normal metal/superconductor (SNS) device fabrication on SOS substrates.

- **Demonstrated** for the first time the fabrication of epitaxial high-temperature superconducting SNS devices on buffer layers on SOS substrates, with device performance comparable to those on standard $LaAlO_3$ substrates. This result is important for application to high-temperature superconducting Josephson mixer fabrication and high-frequency applications that require moderate dielectric constant (<12) substrates. Another important application is the monolithic integration of semiconducting and superconducting devices and circuitry.

- **Fabricated** high-quality edge-geometry SNS weak links on $LaAlO_3$ substrates using cobalt-doped YBCO normal metal layers. Cobalt substitutes for copper in YBCO, which changes the oxygen stoichiometry and suppresses T_c. The advantage of doped YBCO normal metal barriers is that such barriers are thermal-expansion matched to YBCO, which prevents interface strain from causing oxygen disorder and nonuniform conduction. The JPL HTS group is one of only two groups in the world looking at these types of doped YBCO barriers, which may result in dramatically improved SNS device performance.

- **Developed** a new YBCO film-pulsed laser-deposition process utilizing Lanthanum-doped YBCO targets and high oxygen pressures. This process routinely produces films with transition temperatures of 91 K and 0.5-K transition widths, which exhibit excellent microwave performance.

- **Demonstrated** the growth of high-quality epitaxial insulator/YBCO/insulator and insulator/YBCO heterostructures using strontium aluminum tantalate and strontium titanate insulator layers. This multilayer growth capability is essential for HTS integrated circuit applications.

❑ Submillimeter (Terahertz) Receiver Technology

- **Delivered** 547-GHz Nb/AlO_X/Nb SIS mixers for a waveguide receiver. The devices were tested from 460 to 630 GHz and performed well from 460 to 580 GHz, where receiver noise temperatures (double sideband) were below 400 K. The best performance was near the design frequency (540 GHz), where the receiver noise temperature was 200 K. This performance is excellent for this frequency range.

- **Delivered** 500- and 650-GHz Nb/AlO_X/Nb SIS mixers to Caltech for quasioptically coupled receivers based on a twin-slot antenna design. The 500-GHz mixers were tested from 360 to 568 GHz at Caltech. The receiver noise temperature varied from 135 to 150 K in the frequency range of 360 to 490 GHz, rising to 270 K at 544 GHz, and 360 K at 568 GHz. The 650-GHz devices were tested from 490 to 670 GHz, where the noise temperature was found to be comparable to or better than the best waveguide receiver at these frequencies. This is important because quasioptically coupled receivers have no external tuning elements. In the past, use of external tuning elements enhanced the performance of waveguide receivers; but, with this result, the performance penalty of using quasioptically coupled receivers is eliminated. Eliminating these elements is also expected to improve the reliability of the devices, especially in remote operations such as space missions.

- **Delivered** 345-GHz Nb/AlO_X/Nb mixers for SIS waveguide receivers. The noise temperature is <100 K over the frequency range of 270 to 425 GHz, with a best noise temperature of 47 K. These receivers have been installed in the Caltech Submillimeter Observatory in Hawaii as replacements for AT&T Bell Labs Pb junction receivers operating at the same frequency with a noise temperature which is ~150 to 200 K.

- **Delivered and tested** 665-GHz Nb/AlO_X/Nb SIS receivers. The measured noise temperature is <230 K over the frequency range of 570 to 680 GHz, with a minimum of 170 K at 594 GHz. These devices have no integrated tuning elements. Testing above 680 GHz could not be done because of the limitations of the local oscillator. These receivers were installed in the Caltech Submillimeter Observatory in Hawaii.

- **Fabricated** quasioptically coupled twin-slot antenna Nb/AlO_X/Nb mixers at JPL in collaboration with Caltech. These were flown on NASA's Kuyper Airborne Observatory.

- **Delivered** a 2-by-5 focal plane array of $Nb/AlO_x/Nb$ SIS mixers for 500-GHz heterodyne operation to P. Siegal of the JPL Microwave Observational Systems Section (383).

- **Delivered** 216-GHz $Nb/AlO_x/Nb$ SIS mixers to the Smithsonian Astrophysical Observatory/Submillimeter Array at Harvard University.

- **Delivered** 547- and 630-GHz Nb bolometric mixers to R. McGrath of JPL Section 383 for testing. These are the first devices fabricated utilizing this new mixer concept.

- **Demonstrated** first Schottky-collector resonant-tunneling diodes (SCRTDs). These devices have the potential to produce more power at higher frequencies than other resonant-tunneling diodes (RTDs). The SCRTDs are also more easily integrated into circuits than other high-frequency designs.

- **Delivered** barrier-N-N+ diodes to JPL Section 383. In a frequency tripler, these devices produced approximately 200 mW with 4-percent efficiency at 200 GHz. The devices were fabricated using the quartz-lamination/substrate removal process developed last year.

- **Demonstrated** an ultra-low-noise broadband SIS waveguide receiver at 550 GHz. The receiver noise is T_R (DSB) = 200 K at 540 GHz, and the mixer noise is T_M = 180 K. The mixer conversion efficiency is G_M = –6 dB. This is a record result. The mixer uses a carefully designed waveguide circuit. A specially designed superconductive integrated circuit, consisting of a microstrip inductance and radial-stub rf short circuit, is used to resonate the junction capacitance to obtain improved mixer performance. The tunable receiver bandwidth is from 50 to 100 GHz.

- **Demonstrated** an ultra-low-noise broadband SIS waveguide receiver at 625 GHz. The receiver noise is T_R (DSB) = 245 K at 610 GHz, and the mixer noise is T_M = 80 K. The mixer conversion efficiency is G_M = –8.6 dB. This is another record result. This receiver has been used twice at the Caltech Submillimeter Observatory on Mauna Kea in Hawaii and resulted in first detections of HCl in important planetary and astrophysical sources. It is the first submillimeter-wave SIS receiver fully designed and built at JPL to be used in a field observatory. These receiver results represent a significant milestone for low-noise SIS heterodyne receiver technology and show that SIS mixers and integrated rf circuits can operate at up to 90 percent of the energy gap frequency with excellent performance.

- **Systematically studied** for the first time the effects of overlap of photon-assisted tunneling steps on mixer performance at submillimeter wave frequencies. Receiver noise increases by 10 to 40 percent in the region of overlap between the second-order step from negative voltage bias and the first-order step in the positive voltage bias region.

- **Systematically studied** receiver and mixer performance as a function of device and circuit parameters. Initial results indicate that measured circuit resonance frequency is about 10 percent below the design value.

- **Successfully tested** a planar sliding rf short at 100 GHz, the first time a millimeter microwave integrated circuit (MMIC) has been optimized by a mechanical rf tuner. The response of a Schottky detector circuit was improved by 2 dB over the untuned case.

- **Measured by direct-current** Nb hot-electron bolometer mixers for the first time. RF tests at 540 GHz will be performed in a waveguide mixer circuit. This transition-edge device uses a submillimeter geometry to shorten thermal response time and increase IF bandwidth.

- **Demonstrated** the first integrated subharmonically pumped anti-parallel-pair Schottky barrier diode mixer using the new quartz upside-down integrated device (QUID) process developed at JPL's Microdevices Laboratory. Noise temperature at 215 GHz is within 20 percent of the best reported for any such mixer at this frequency.

- **Demonstrated** the first fully operational superconducting planar array receiver using dipole array on a dielectric-filled parabola. Receiver noise temperatures under 100 K were achieved at 230 GHz, only a factor of two higher than the best single element waveguide receivers at this frequency using similar superconducting devices.

- **Demonstrated** the first tripler measurements using integrated bbBNN (back-back barrier-intrinsic n-type) devices designed and fabricated at the JPL Microdevices Laboratory. Tripling efficiencies of 4 percent were achieved at 220 GHz, the highest yet reported.

❑ **Semiconducting Materials: Growth and Characterization**

- **Demonstrated** the feasibility of a new technology to allow the fabrication of a variety of silicon/oxide heterostructures with a wide range of potential applications.

- **Developed** novel molecular beam epitaxy (MBE) growth techniques for improved control over small epitaxial Ge particles embedded in silicon, where the ultimate goal is quantum-sized particles exhibiting luminescence.

❑ Electronic Device Technology

- **Demonstrated** the first complementary metal oxide semiconductor (CMOS) active pixel image sensor.

- **Fabricated** the first interdigitated pixel PIN cosmic ray detector in the JPL Microdevices Laboratory and demonstrated its operability.

- **Demonstrated** the first Schottky-collector resonant-tunneling diodes (SCRTDs). These devices have the potential to produce more power at higher frequencies than other resonant-tunneling diodes (RTDs). The SCRTDs are also more easily integrated into circuits than other high-frequency designs.

- **Delivered** barrier -N-N+ diodes to JPL Section 383. In a frequency tripler, these devices produced approximately 200 mW with 4 percent efficiency at 200 GHz. The devices were fabricated using a quartz-lamination/substrate removal process developed last year.

❑ Microinstrument Technology

- **Developed** a new mechanical suspension that offers an increase in accelerometer response by decreasing the suspension resonance frequency, while maintaining a compact package and simple robust structure.

- **Demonstrated** a reduction in resonance frequency from 40 to 1 Hz and an improvement in sensitivity of $40^2 = 1600$ times.

- **Developed** a new feedback circuit that provides wide bandwidth response (dc to 50 Hz) with this low-frequency suspension.

- **Extended** instrument-sensitivity goals from 10^{-9} to 10^{11} g while maintaining a compact and robust sensor structure. This is achieved through new mechanical structure and feedback control methods.

- **Selected** as a flight instrument candidate for the In Space Technology Experiments Program (IN-STEP) was the JPL microseismometer/microaccelerometer.

- **Fabricated and successfully tested** a new compact micro-hygrometer device, which has been selected for a flight demonstration in a NASA high-altitude aircraft.

- **Designed**, **fabricated, and successfully tested** a micro-machined silicon thermal-conductance absolute-pressure sensor. This device provides the sensitivity required for applications on Mars' surface and in Earth's upper atmosphere without the need for a vacuum reference.

- **Employed** micromachining to fabricate a temperature sensor for atmospheric temperature measurement in low-density atmospheres. Applications are on Mars' surface and in Earth's upper atmosphere.

- **Developed** a unique micromachined silicon sensor for direct measurement of the wind on Mars and the Earth. This centimeter-scale device accurately detects the flow of atmospheric gases through a microscopic channel. Applications of this device also are expected in aircraft aerodynamic flow measurements.

❑ **Adaptive Optics**

- **Designed and fabricated** a micromachined closed-loop electro-statically-actuated reflector (μCLEAR).

- **Developed** micromachining methods for membrane fabrication.

- **Demonstrated** electrostatically-controlled actuation of a 25-mm-diameter μCLEAR device.

- **Demonstrated** a 5l (l = .6 μm) deflector for the 9-mm-diameter μCLEAR device.

- **Verified** the membrane model of deflection vs. the voltage relationship for a 9-mm-diameter μCLEAR device. Voltage requirements and resulting mirror shape are in good agreement with theory.

- **Designed and fabricated** a micromachined tip/tilt mirror assembly (no membrane).

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J. A. Stroscio and W. J. Kaiser, editors, chap. 7, vol. 27, Academic Press, 1993.

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"A Miniature, High-Sensitivity, Broadband Accelerometer Based on Electron Tunneling Transducers,"
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T. B. Gabrielson,
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"Characterization of Hot Carrier Transport in Semiconductor Structures,"
S. J. Manion,
Physics and Chemistry of Semiconductor Interfaces, PCSI-20, Williamsburg, VA, January 29, 1993.

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"BEEM Investigation of Strained Metal/Semiconductor Systems,"
L. D. Bell
40th National Symposium of the American Vacuum Society, Orlando, Florida, November 17, 1993.

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W. J. Kaiser,
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M. H. Hecht,
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Superconductivity

- <u>Publications</u>

"Growth of $YBa_2Cu_3O_{7-d}$ on Alkaline Earth Fluoride Substrates and Thin Films,"
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"Superconducting Microbolometers Utilizing Epitaxial $YBa_2Cu_3O_{7-x}$ Thin Films,"
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Submillimeter (Terahertz) Receiver Technology

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II. Photonics

OVERVIEW

This section concentrates on optoelectronic materials and devices. Optical processing is included in the section on Advanced Computing. Optoelectronic devices that generate, detect, modulate, or switch electromagnetic radiation are being developed for a variety of space applications. The program includes spatial light modulators, solid-state lasers, optoelectronic integrated circuits, nonlinear optical materials and devices, fiber optics, and optical networking photovoltaic technology and optical processing.

1993 MAJOR TECHNICAL ACHIEVEMENTS

❑ Lasers

- **Demonstrated** the first continuous operation of InGaAs/InP lasers at wavelengths up to 2.07 µm. These lasers are essential for injection seeding of Tm:YAG solid-state lasers for eye-safe light detection and ranging (LIDAR) and spectroscopy applications.

- **Developed** very efficient, high-power InP-based semiconductor lasers at 1.43 µm to perform in-situ gas phase monitoring of CO_2. The eventual goal is the development of a laser spectrometer offering significantly reduced mass, size, and power requirements.

- **Developed** an electrically tunable single-mode laser with hundreds of gigahertz of continuous tunability. The potential of an integrated pair of tunable lasers being used to generate microwave and submillimeter signals is being investigated.

- **Patterned** gratings with fine pitch control allowing arbitrary lasing wavelength, for DFB lasers.

❑ Optoelectronic Materials and Characterization

- **Developed** rapid specimen preparation techniques for the observation of epitaxial diamond- and nitride-based optoelectronic materials.

- **Demonstrated** a novel laser-ablation technique for the thinning of natural diamond substrates. Bulk diamond specimens were characterized by transmission electron microscopy (TEM) using this technique.

- **Characterized** heteroepitaxial diamond films grown on Si. Detected the presence of an interfacial SiC layer between the diamond and the Si substrate.

- **Examined and published** the first TEM characterization results from short period superlattices of GaN/AlN grown by switched atomic layer epitaxy (ALE) on sapphire substrates.

❑ Optoelectronic Integrated Circuits

- **Designed**, **fabricated**, **and installed** a state-of-the-art low damage chemical-assisted ion-etching (CAIBE) system at the JPL Microdevices Laboratory. This system will be used for fabrication of submicrometer optoelectronic integrated circuits (OEIC) structures.

- **Accomplished** growth of high-quality InGaAsP epitaxial layers by the newly installed state-of-the-art metallorganic chemical vapor-deposition (MOCVD) reactor. The new growth capability enables the fabrication of semiconductor lasers and optoelectronic components.

❑ Infrared Detectors

- **Demonstrated** the first stacked SiGe/Si heterojunction internal photoemission (HIP) infrared detector with a factor of 4 performance improvement compared to the single-layer HIP detector, suitable for large focal plane array applications in the 3 to 20-μm spectrum.

- **Developed** a detector model for the SiGe/Si HIP infrared detector, providing a figure-of-merit for further detector optimization.

- **Demonstrated** 3-times quantum-efficiency improvement at 4 μm compared to the conventional PtSi detector by extending the cutoff wavelength to 6.5 μm utilizing the doping-spike PtSi infrared detector operating at 70 K.

- **Fabricated and delivered** 32 long-wavelength infrared detector arrays (256 x 256) for bonding to the readout multiplexes.

- **Demonstrated** a novel normal-incidence optical-coupling technique based on scattering from a random reflector monolithically etched into the top of a quantum well infrared photodetector (QWIP). Achieved nearly an order of magnitude improvement in optical absorption, responsivity, and detectivity as compared to a one-dimensional grating or 45-degree angle of incidence coupling.

- **Demonstrated** a bound-to-continuum state GaAs/$Al_xGa_{1-x}As$ infrared hot electron transistor with peak response at l_P = 16.3 µm. This device uses a bound-to-continuum QWIP as a photosensitive emitter and a wide $Al_xGa_{1-x}As$ barrier between the base and the collector as an energy discriminating filter. An excellent photo-current transfer ratio of a_p = 0.12 and very low dark current transfer ratio of $a_4 = 7.2 \times 10^{-5}$ are achieved at a temperature of T = 60 K.

- **Dramatically reduced** the dark current by many orders of magnitude and thereby significantly increased detectivity by increasing the quantum well barrier width, incorporating spacer layers between the contacts and the multiquantum well region, and optimizing the materials growth parameters. For $In_{0.2}Ga_{0.8}As$ /GaAs quantum well infrared photodetectors having a cutoff wavelength l_c = 18.3 µm, we have achieved $D^* = 1.8 \times 10^{10}$ cm√Hz/W at temperature T = 40 K.

❑ Nonlinear Optics and Optical Processing

- **Developed** nonlinear optical chromophores that resulted in guest/host electro-optic polymer with $|r_{33}|$ = 52 pm/V at 820 nm, i.e., twice that of $LiNbO_3$. These polymer systems give a nonre-sonant r33 = 5 pm/V at the important telecommunication wave-length of 1300 nm. While these results were obtained with 2 mole percent dye, an order of magnitude increase is feasible by covalent attachment, suggesting that values at 1300 nm of 50 pm/V could be realized. These materials have great potential for low-cost optical switching and modulation components.

- **Designed and synthesized** NLO chromophores with high thermal stability and large nonlinearity, based on reduced aromaticity bridges and novel acceptors developed at JPL. The best chromophore to date has mb > 8000 x 10^{-48} ESU and exhibits <10-percent decomposition at 230 C, making it a promising candidate for thermally stable electro-optic polymers. Collaboration being developed with Enichem America to transfer and develop technology for commercial device applications.

- **Determined** the electro-optic coefficient of the JPL-developed organic salt electro-optic crystal DAST to be 100 pm/V at 1064 nm. This material has one of the highest electro-optic figures of merit known.

- **Developed** process for top seeded solution growth of DAST crystals. Obtained specimens of 1-cm dimension, which are suitable for device fabrication.

- **Demonstrated** a high-contrast (>100:1) optical switch at 633 nm using the JPL organic crystal, DAST. (Demonstration was in collaboration with GE, and now with spin-off company, MOEC.)

- **Implemented** strategy of optimization of third-order nonlinearity to develop molecules with a nonlinearity twice that of b-carotene.

- **Performed** experimental studies that demonstrate that the dependencies of the second- and third-order molecular nonlinear polarizabilities on the degree of polarization of the molecule are related, with the third-order dependence being proportional to the derivative of the second-order response.

- **Developed** a unified theoretical picture for linear and nonlinear polarization that relates geometric and electronic structure to the dipole moment and polarizabilities of conjugated organic molecules.

- **Synthesized** soluble variants of highly nonlinear-absorptive heavy-atom containing phthalocyanines (e.g., indium) for incorporation at high concentration in host materials for solid-state optical limiter device development.

- **Demonstrated** multiple plate limiter design using JPL-developed phthalocyanine nonlinear absorptive optical limiter materials leading to nonlinear attenuation of nanosecond-visible laser pulses by a factor of 200 with a device that transmits 65-percent at ambient light levels.

❑ Space Environmental Effects on Materials

- **Demonstrated** ground-based broadband proton radiation source for simulation of the natural space environment.
- **Predicted preflight outcome** of STRV-1 flight radiation experiments based on ground-based data.
- **Published** *Preliminary Protocol for Atomic Oxygen Testing of Materials.*
- **Published** *Cleanliness Diagnostic Techniques for Optical Surfaces Report.*
- **Published** *Effects Data for Molecular Contamination on Cryogenic IR Sensor Surfaces Report.*
- **Organized** short-duration space flight experiment opportunities for exposure of select materials to AO fluences (10^{20} atoms/cm^2).
- **Coordinated** and managed integration of flight experiment into host spacecraft.
- **Demonstrated** and validated space flight operation of a miniature active atomic oxygen fluence-measuring instrument.
- **Assessed** current knowledge of micrometeorites and debris (MM&D) in mid-Earth altitudes.
- **Assessed** types of impact damage and the probabilities of spacecraft instrument survival.
- **Identified** and characterized flight-ready MM&D sensors that can be "piggy-backed" on spacecraft.

❑ Photonics Systems

- **Developed** a prototype remote-sensing polarimetric hyperspectral imaging system. It uses an acousto-optic tunable filter of TeO_2 as the fast programmable wavelength sorter and polarizer. Preliminary field tests have illustrated capabilities of the technology to characterize natural and manmade objects in remote environments.

❑ Remote-Sensing Technology

- **Developed** an acousto-optic tunable filter, polarimetric hyperspectral imaging prototype system.
- **Successfully performed** several field tests of the system, including one at Ft. Huachuca, Arizona.
- **Developed** algorithms to process and analyze polarimetric hyperspectral images.
- **Illustrated** technology capability to measure signatures of natural and manmade objects in different environments.
- **Observed** evidence that the technology is able to detect camouflaged objects in clutters.
- **Demonstrated** a novel thin-film far-infrared filter based on a Fabry–Perot structure with mirrors consisting of electron-beam-lithography-patterned metallic layers.

❑ Binary Optics

- **Fabricated** a 64-phase-level diffraction-limited Fresnel lens having an 89-percent efficiency by direct-write, variable-dose e-beam exposure of polymethylmethacrylate (PMMA).
- **Fabricated** computer-generated phase holograms demonstrating better than $\pm\lambda/30$ phase precision, leading to high-performance optical fan-out and interconnect devices.

TECHNICAL PROGRESS REPORTS

Spatial Light Modulators

- ❑ <u>Publication</u>

  "Object-Oriented Classification for Software Reuse: Knowledge-Based Overview,"
  B. Beckman and M. K. Summers,
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- ❑ <u>Presentation</u>

  "Project Management: A Multimedia Perspective,"
  S. Shen,
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- ❑ Publication

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  S. Forouhar, S. Keo, A. Larsson, A. Ksendzov, and H. Temkin,
  Electron Lett., vol. 29, no.7, pp. 574–576, 1993.

- ❑ Invited Presentation

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  S. Forouhar,
  Lasers and Electro-Optics Society, Jet Propulsion Laboratory, Pasadena, CA, October 14, 1993.

Optoelectronic Materials and Characterization

❑ Publications

"Below Band-Gap Laser Ablation of Diamond for Transmission Electron Microscopy,"
T. George, M. C. Foote, R. P. Vasquez, E. P. Fortier, and J. B. Posthill,
Applied Physics Letters, vol. 62, p. 2880, 1993.

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  A. R. Johnson, D. T. H. Liu, S. Forouhar, G. F. Lutes, J. Maserjian, and E. R. Fossum,
  Optical Engineering Journal, vol. 33, no. 67, p. 2013, June 1994.

Infrared Detectors

- Publications

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"Infrared Photodetectors with Tailorable Response Due to Resonant Plasmon Absorption in Epitaxial Silicide Particles Embedded in Silicon,"
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- Publications

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III. Advanced Computing

OVERVIEW

Advanced concepts in hardware, software, and algorithms are being pursued for application in next-generation space computers and for ground-based analysis of space data. The research program focuses on massively parallel computation and neural networks, as well as optical processing and optical networking, which are discussed in the Photonics Section. Also included are theoretical programs in neural and nonlinear science, and device development for magnetic and ferroelectric memories.

1993 MAJOR TECHNICAL ACHIEVEMENTS

❑ Parallel Computation

- **Completed** a simulation model for an all-optical data path communication network with microsecond routing latency at 98 percent of input loading.

- **Developed** three-dimensional, coupled, integral-equation, finite-element electromagnetics code for analysis of irregular scatterers, consisting of inhomogeneous, possibly anisotropic, materials.

- **Continued the enhancement of** existing parallel, integral-equation, finite-element, finite-difference, and two-dimensional coupled approach codes and developed decomposition and mesh-refinement tools.

- **Exchanged** technical information with the aerospace community and worked with parallel-processing vendors, supporting in-house visitors working with parallel electromagnetic (EM) codes, development tools, and parallel-processing hardware.

- **Implemented** three-dimensional electromagnetic plasma particle-in-cell code on the Intel Delta Touchstone parallel computer with very high (>95-percent) parallel efficiency.

- **Designed and demonstrated** a heterogeneous distributed computing environment, integrating remote High-Performance Computing and Communication (HPCC) sites, local workstations, and a video archive system using transmission control protocol/ Internet protocol (TCP/IP) data communication protocol and AVS visualization system. The environment enables a user to pipe computation results, as computed from a remote supercomputing center, to the user's workstation for post processing and visualization.

- **Demonstrated** the integration of parallel-mesh partitioning and parallel-mesh refinement code for two- and three-dimensional unstructured meshes on up to 512 nodes of the Intel Delta machine. This tool is applicable to parallel finite element and finite volume applications.

- **Implemented** two- and three-dimensional parallel multigrid Poisson solvers on Intel's Gamma, Delta, and Paragon computers for Dirichlet boundary conditions. Three grid-partition strategies have been implemented, demonstrating scalable performance on up to 512 Delta nodes.

- **Designed and implemented** a parallel whole Earth-rendering algorithm on the Intel Touchstone Delta system, Intel Paragon, and Cray T3D. The renderer is designed to be scalable and efficient for massively parallel supercomputers and very large scientific datasets.

- **Designed and implemented** a framework for parallel discrete-event simulation, which was delivered to the Advanced Research Projects Agency and U.S. Air Force.

- **Produced** a 90-second animation video, "Flight Over Haleakala," using the Intel Delta and the Maui Landsat dataset.

- **Demonstrated** "Interactive Mojave Desert Flyby" in real-time at "Supercomputing '93," in Portland, Oregon using the whole Earth renderer running on the Intel Paragon, the HiPPI Frame buffer, and the Silicon Graphics Flight Simulator.

- **Implemented and demonstrated** geographically distributed discrete event simulation in conjunction with Los Alamos, the National Test Facility (NTF), and the Naval Research Laboratory.

❑ Neural and Analog Computing

- **Customized and delivered** a software simulator called “Strike Planner” to the Naval Air Warfare Center, China Lake. This software simulates a novel, massively parallel, computing resource allocation processor (RAP) architecture (patented by JPL) for solving a class of computationally intensive dynamic-assignment problems encountered in military domain. It performs weapon-to-target assignments for up to 400 weapons and 400 targets to obtain an optimal or "good" assignment out of a very large number of possibilities (factorial 400). Furthermore, it enables solutions of many-to-many associations, as well. The simulator is a precursor to an application-specific integrated circuit (ASIC) chip that will perform these assignments at speeds of a few milliseconds, over 4 orders of magnitude faster than conventional computing techniques.

- **Completed** hardware fabrication of (and software development for) the embeddable reconfigurable neuroprocessor VME card (NNH-V-RC-05). This card holds eight of our cascadable composite (32-neuron/992-synapse) building block chips and provides up to 64 input neurons, up to 8000 programmable analog synapses, and up to 64 hidden and/or output neurons. Its performance was demonstrated on the representative problem of map separates. With its streamlined VME interface, this card is a step closer to emerging, high-performance host machines such as DEC Alpha.

- **Successfully tested** a space environmental effects (SEE) board at JPL with two configured neural networks using very-large-scale integration (VLSI) implemented chips. It was one of three selected JPL experiments for temperature, vacuum, and vibration (flight readiness). The board was flown on a Space Technology Research Vehicle (STRV) launched on February 23, 1993 by the British Defense Research Agency (DRA). During its one-year mission in geotransfer orbit, it studied the effects of the space-radiation environment on the fault-tolerance of neural network hardware.

- **Developed and demonstrated** a new hardware-implementable architecture for car license plate identification using a computer simulation. This architecture utilizes morphological and wavelet transform processing that offers an enhanced discrimination capability compared to the state-of-the-art digital signal-processing approach. Optoelectronic implementation of the simulated architecture would result in more than a hundred-fold increase in processing speed over the state-of-the-art approach. Interest has been expressed by law enforcement agencies and the customs/ border control.

- **Designed, fabricated, and demonstrated** a multiphase Dammann grating at the JPL Microdevices Laboratory. This grating is the first of its kind, fabricated with a continuous e-beam phase modulation technique, achieving high efficiency (> 80 percent) and high resolution (> 20 lines/mm).

- **Developed** a new "Focal Plane Array Window Grabber" architecture for extremely high-speed signal processing of images obtained at over 1000 frames per second. This architecture is based on our low-power neural network chips and Irvine Sensors Corporation's "sugarcube" chip-packaging technology. This will be useful not only for on-board an interceptor as artificial vision, but also for high-speed analysis of cartographic or satellite data, and for on-line control of product quality (or process monitoring) in a manufacturing environment.

- **Completed** a layout for a 64-by-64 active-pixel-sensor (APS) array imager, incorporating a recently developed fixed pattern noise reduction circuitry. This work, in collaboration with JPL Section 381, has the overall goal of combining intelligent and adaptive processing capabilities directly on the focal plane of the sensor array.

- **Demonstrated** that a neural network can be trained to recognize surface mines (received from the U.S. Navy) by only their spectral signatures. The multispectral images used for this demonstration came from JPL's acousto-optic tunable filter (AOTF)-based imaging system. Encouraged by this result, the U.S. Navy sponsor has sent a new set of realistic imagery data to JPL for evaluation.

- **Demonstrated** object discrimination by using a polarimetric laser-probing technique in the laboratory. When compared to brown soil of similar color and texture, it successfully discriminated metallic ordinance fragments (with an over 30-year-old rusty surface). The laser-probing technique is also effective in discriminating other man-made objects that are similar in appearance, such as glass and plastics. This experiment represents an important step towards the environmental clean-up task sponsored by the Army Corps of Engineers.

- **Accomplished** the installation of our reconfigurable neuroprocessor hardware (PC card) onto the ethernet network, an important technical (and programmatic) milestone. Now our neural network hardware can be accessed and used remotely by selected users, to process their own data, taking full advantage of the computing speed offered by the parallel hardware without duplicating the hardware at their site.

- **Developed** an innovative wavelet processor for the detection of the orientation, scale, and location of multiple targets embedded in severe noise and clutter. Computer simulations have demonstrated excellent results. A new complex-valued e-beam wavelet filter is designed for experimental demonstration of this technical approach.

- **Completed** ground-radiation tests on neural net chips identical to the ones flown on the British Space Technology Research Vehicle (STRV) payload. These tests provide baseline characteristics of the hardware radiated with up to a 200-kRad total dose, the expected level of exposure during the first year of the STRV mission. The characteristics showed operational fault tolerance till 140-kRads total dose, at which level some of the analog synapse-neuron devices developed excessive leakage and failed to perform as designed.

- **Developed**, in collaboration with Irvine Sensors Corporation, a conceptual architecture for three-dimensional VLSI integration of neural network chips into a "sugarcube" for Ballistic Missile Defense Organization’s (BMDO) On-Board Real-Time Target Acquisition, Discrimination, Detection, and Homing Application. This will lead to a realization of several thousand fully parallel analog neurons in an extremely compact, low-power package for the time-critical Strategic Defense Initiative (SDI) application.

- **Applied** an innovative neural network-inspired technique, for the first time, to NASA's complex problem of retrieval of atmospheric moisture profiles from measured microwave radiometry. A fixed topology of feed-forward neural network, trained with our new quick-prop learning algorithm, was used to capture the inverse mapping from a subset of 12 available microwave channels. Results indicate that neural network technique (resulting in an rms deviation of 0.38) performs better than the results obtained by conventional statistical regression analyses (rms deviation of 0.42).

- **Experimentally demonstrated**, for the first time, a holographic technique for the synthesis of bipolar neural synapses in the laboratory. This is a result of an innovative use of electrically controllable birefringence in a liquid crystal light valve for reference phase control. The implementation of inhibitory synapses enables a true discrimination capability for target recognition.

- **Extended** Kalman filter learning for neural networks to networks with multiple inputs and outputs in software simulation, to make it relevant to the BMDO problem of adaptive guidance and control of an interceptor. An analysis of the proposed hardware implementation in a selected high-precision digital version suggests that complete learning can indeed be accomplished on-line within the available window of only a few seconds. This work was performed jointly by JPL and the University of California–Irvine.

- **Experimentally demonstrated**, for the first time, a joint transform wavelet processor in the laboratory. This powerful real-time implementation method is for image enhancement and segmentation at high resolution, as a precursor to automatic target recognition.

❑ Neurocomputing Theory and Nonlinear Science

- **Developed** a new class of algorithms for solving time-dependent partial differential equations (PDEs) on massively parallel supercomputers. Such PDEs are at the heart of many scientific and engineering applications as well as grand challenge problems. Usually, they are numerically simulated by discretization in time and space, and by applying a time-stepping procedure to data and algorithms potentially parallelized in the spatial domain.

  In a radical departure from such a strictly sequential temporal paradigm, a concept of time-parallelism was demonstrated, which allows the marching in time to be fully parallelized. This demonstration is achieved by using a set of transformations based on eigenvalue-eigenvector decompositions of the matrices involved in discrete formalism. The resulting time-parallel algorithms possess a highly decoupled structure, and can therefore be efficiently implemented on emerging, massively parallel, high-performance supercomputers with a minimum of communications and synchronization overhead. Time parallelism has been shown to be feasible. A proof-of-concept demonstration of the basic ideas was also successfully carried out on three examples: a two-dimensional heat equation, the Schrodinger equation, and an electromagnetic scattering problem. This approach also presents outstanding opportunities for technology transfer to U.S. industry, particularly in the areas of computational electromagnetics and seismic modeling.

- **Developed and demonstrated** novel neural learning theory in terms of nonlipschitzian dynamics and adjoint operators. This new methodology enables highly efficient computation of the gradient of an objective function or functional within the various parameters of the network architecture. Specifically, it combines the advantage of dramatic reductions in computational complexity inherent in adjoint methods with the ability to solve, for temporal (i.e., trajectory) learning, the adjoint equations forward in time. Not only is a large amount of computation and storage saved, but the handling of real-time applications also becomes possible. Results show that learning time is reduced by one to two orders of magnitude in comparison to the best previously published benchmark results, while trajectory tracking is also significantly improved. This work lays the foundations for new approaches to nonlinear system identification, and efficient spatiotemporal pattern processing.

- **Discovered** a new method for global optimization of multiextremal functions, based on the novel concept of "Terminal Repeller Unconstrained Subenergy Tunneling."

- **Demonstrated** the new method for global optimization of multiextremal functions, which is over 100 times faster than competing state-of-the-art approaches, on the standard **SIAM** benchmarks. This method should be highly valuable for many space, energy, and defense applications.

- **Developed** a methodology to solve certain classes of partial differential equations on synchronous neural hardware. The corresponding algorithms were implemented and benchmarked (in simulation) for the Korteweg–de Vries (soliton) and heat equations. In view of projected computational capabilities of neural optoelectronic hardware, this breakthrough approach is expected to have a profound, long-term impact on modeling complex phenomena of relevance to NASA and the Departments of Defense and Energy in the areas of geophysics, space science, and aeronautics. This methodology received a NASA Major Monetary Award for technical inventions in November 1993.

❑ Data Storage

- **Demonstrated**, with Honeywell, Inc., the successful modification of a fabrication process from GaAs to a vertical bloch line (VBL). This demonstration helps realize a manufacturable fabrication process for VBL devices.

- **Demonstrated** the ability to match the operating points of input/output data lines with minor loop storage areas. This demonstration is an important precursor for demonstrating a complete storage chip with data input/output and data storage functions.

- **Demonstrated** horizontal bloch line (HBL) nucleation as a VBL bit injection mechanism for VBL writing. This effect on magnetic domain walls was observed experimentally and quantified and analyzed successfully using micromagnetic supercomputer simulations.

- **Simulated** VBL bit propagation using micromagnetic computation on the CM-2 Connection Machine supercomputers. This simulation showed dynamic propagation of VBL bits for propagation rates in excess of 10 Mbits per second per minor loop, and suggests methods for improving bit definition and materials selection for improving device operating margins.

- **Developed** an improved epitaxial yttrium-iron-garnet (YIG) material composition for use in upcoming VBL chips. This material supports VBL areal densities of 25 Mbits per square centimeter and has been designed to reduce chip power requirements by approximately 30 percent when compared to previous materials.

- **Defined** 64- and 256-Mbit VBL chip architectures that satisfy important commercial, as well as governmental, requirements.

- **Demonstrated** an advanced electro-magneto-optic test system for making detailed measurements on VBL chips. This system can detect domain wall displacements with 30-nm precision using sequenced pulses with a timing jitter less than 500 ps.

❑ Software Engineering and Computer Science

- **Upgraded** the Hypermedia library technology (HyLite) and ported it to the Macintosh environment. Ported the Macintosh graphical user interface to the Sun environment and **created** separate versions of HyLite to support both CD and hard disk data sources. Attention was focused on providing support to the PDS user and enhancing PDS CD-ROM capabilities. A Memorandum of Understanding was established with the Digital Data Library. In addition, a major effort was devoted to establishing working relationships with potential HyLite users, with industry for technology transfer, and with colleges and universities.

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IV. Custom Microcircuits

OVERVIEW

The goal of this program is to develop custom microcircuit technology, also known as application-specific integrated circuit (ASIC) technology, for use in flight and ground programs. Supporting this effort are activities to investigate the effects of the space environment, and particularly ionizing radiation, on microcircuits and to develop a space-qualification methodology. Another aspect of the program emphasizes innovative applications of custom microcircuit technology to image and signal processing and communications.

1993 MAJOR TECHNICAL ACHIEVEMENTS

❑ Quality Assurance and Space-Qualification Methodology

- **Evaluated** the Honeywell 1060 Gate Array Test Coupon, which is to be used for assessing the reliability of flight gate arrays.
- **Delivered** the Radiation and Reliability Assurance Experiment (RRELAX) for the Clementine Mission to be launched January 25, 1994.
- **Delivered** the Radiation Monitor (RADMON) to the Space Technology Research Vehicle (STRV-1b) to be launched February 23, 1994.
- **Delivered** a RADMON p-FET dosimeter for the SAMMES-1a Mission to be launched in 1994.

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Quality Assurance and Space-Qualification Methodology

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V. Appendix

CSMT–CALTECH CAMPUS COLLABORATIONS

H. Atwater	Giant magnetoresistance multilayers and materials; GeSn alloys for infrared sensing
J. D. Baldeschwieler	Scanning tunneling microscopy
J. Burdick	Global optimization
K. P. Giapis	Semiconductor etching
T. Gottschalk	Parallel polygon manipulation algorithms for design automation; radar track initiation software for multisensor tracking and surveillance systems; simulation and tracking software developed for theatre missile defense and missile defense environments
R. H. Grubbs	Nonlinear optical polymers
H. Keller	Parallel plasma simulation
S. Karmesin	Parallel plasma simulation
N. Lewis, C. Karp	Surface electrochemistry patterns
V. Lubecke	Submillimeter wave circuits
R. Mewaldt	Cosmic ray detectors
T. Phillips	Submillimeter receivers
D. Psaltis, D. Marx	Subwavelength optical patterns
J. Rosen	Computer-generated holograms
M. Roukes, D. Harrington	Integrated acousto-optic patterns; piezoelectric thin-film devices; intrinsic noise and fundamental sensitivity limits of tunneling displacement sensors
D. B. Rutledge	Grid amplifiers and other quasioptical microwave/ millimeter-wave concepts; submillimeter-wave circuits

R. Schoelkopf	High-temperature superconductor Josephson mixers
N. Scoville	Submillimeter receivers
M. Segev	Volume holographic data storage
K. Vahala	Patterned growth of GaAs for quantum dots and wires; lithography of quantum dots
A. Yariv	Optoelectronic computing
N.-C. Yeh	High-temperature superconductor, high-field magnetic properties
J. Zmuidzinas	Submillimeter receivers

CSMT–OTHER COLLABORATIONS

D. Andes (Naval Weapons Center)	Neurocomputing algorithms for target detection in cluttered backgrounds
A. Bagneres (U. of Grenoble)	Micromagnetic supercomputer simulations
B. Beckman (Microsoft, Inc.)	Knowledge-based software
D. Beratan (U. of Pittsburgh)	Theory of optical nonlinearities and electron transfer
H. Bozler (USC) P. Echternach	Single-electron transistor
J. U. Brackbill (Los Alamos Scientific Laboratory)	Parallel plasma simulation
J. L. Bredas (U. of Mons, Belgium)	Theoretical studies of conjugated organic molecules
J. Brock (TRW)	DFB gratings
D. Casasent (Carnegie-Mellon U.)	Optical processing
J. Champine (Cray Research, Inc.)	Parallel rendering algorithm development
L. T. Cheng (Dupont)	Hyperpolarizabilities of organics
R. Colton (Naval Research Laboratory)	Magnetometer
R. Culbertson (Arizona State U.)	Ion beam analysis of materials
T. E. Cushing (Altadena Instruments)	Development of electronics and packaging for underwater testing of tunneling accelerometers

T. Crowe (U. of Virginia)	Semiconductor devices
N. Dagli (U. C., San Diego) M. Thomas	Electron waveguides
L. Dalton (USC)	Electro-optic polymer modulator
D. Dapkis (USC)	HDWDM components in photonic integrated circuits; DFB gratings
J. M. Dawson (U. of California)	Parallel plasma simulation
V. Decyk (U. of California)	Parallel plasma simulation
R. van de Geijn (U. of Texas, Austin)	High-performance in-core parallel direct solver
A. Dickinson (AT&T Bell Labs)	Active pixel image sensors
S. Dixit (Lawrence Livermore National Laboratory)	Amplitude leveling phase plate
T. Dowling (Massachusetts Institute of Technology)	Explicit planetary isentropic coordinate atmospheric model
G. Dreyfus (ESPCI, Paris, France)	Neural networks
B. Dunn (UCLA)	Sol-gel nonlinear optical materials
J. East (U. of Michigan)	Submillimeter-wave mixer analysis
P. Encrenaz (Ecole Normale Superieur, Paris, France)	Superconductor–insulator–superconductor receivers
N. Erickson (U. of Massachusetts)	Submillimeter-wave multipliers

S. Ermer (Lockheed)	Molecular design of chromophores
M. Forrester (Westinghouse Science and Technology Center)	High-temperature superconductor digital electronics
D. W. Forslund (Los Alamos Scientific Laboratory)	Parallel plasma simulation
T. Gabrielson (NAWC)	Accelerometer
A. Garito (U. of Pennsylvania)	Hyperpolarizabilities of squaraines, negative hyperpolarizabilities
E. Gelende (Duke U.)	Neural networks
H. Gibbs (U. of Arizona) F. DeColstoun	Vortex phase plate
A. Gmitro (U. of Arizona) B. Velasquez	Optical interconnect holograms
K. Goser (U. of Dortmund)	Neural networks
J. Green (Oxford U.)	Photoelectron spectroscopy of organic and organometallic NLO materials
D. Greve (Carnegie-Mellon U.)	Silicon long-wavelength infrared active pixel sensor
A. Grimshaw (U. of Virginia)	Mentat, an object-oriented parallel processing environment
J. Hardy (Geodynamics Corp)	Correct distributed simulation protocol
R. Haas (Aerojet Electronics Systems)	Waveguide horns
J. Herring (Hughes)	256 x 256 long-wavelength infrared focal-plane array

S. S. Iyengar (California State U. of Los Angeles)	Sensor fusion
V. Jackson (Intel)	Supercomputer demonstration
B. Jallali (UCLA)	Space robotic vision sensors
A. Jen (EniChem America) R. Minini	Electro-optic polymers, NLO chromophores
B. Johnson (Honeywell)	High-temperature superconductor bolometers
P.A. Kaaret (Columbia U.)	Development of silicon lobster-eye x-ray optics
L. P. B. Katehi (U. of Michigan)	Waveguide circuits
R. Keller (Harvey Mudd College)	Hypermedia library technology (HyLite)
C. Kirchhof (Cray Research, Inc.)	Parallel rendering algorithm development
M. A. Khan (APA Optics, Inc.)	Characterization of wide band-gap semiconductors
A. Kleinsasser (IBM)	High-temperature superconductors superconductor/normal metal/ superconductor device analysis: superconductor–insulator–superconductor junction analysis
J. A. Kovacich (Eaton Corporation)	Tunneling magnetometer program
A. Kussmaul (MIT–Lincoln Laboratory)	High-temperature superconductors
D. L. Kwong (U. of Texas)	Porous Si and SiGe
A. G. Larsson (Chalmers U.)	Molecular beam epitaxy growth and semiconductor lasers

T. Lee (Kodak)	Active pixel image sensors
B. F. Levine (AT&T Bell Laboratories)	Infrared detectors
J. Luine (TRW)	HTS digital electronics
P. Malin (Duke U.)	Borehole seismometers
R. L. Marcus (Central State U.)	Hypermedia library technology (HyLite)
William Martin (Analysis Consultants)	Dark current reduction in silicon far-infrared detectors
P. Miles (Logicon/RDA)	Nonlinear absorptive optical limiters
F. Namavar (Spire Corporation)	Porous silicon
S. Narathong (U. of Wisconsin–Platteville)	Neurochip designs
G. M. Nathanson (U. of Wisconsin)	Molecular-beam scattering from surfaces
J. Norgard (U. of Colorado, Colorado Springs)	Validation studies
S. Palfrey (David Sarnoff Research Center)	Monolithic long-wavelength infrared focal-plane array
P. Pellegrini (Rome Laboratory)	PtSi infrared detector
A. Persoons (U. of Leuven, Belgium)	Hyper-Raleigh scattering technique
B. Pierce (Hughes Aircraft Company)	Theoretical studies of conjugated organic molecules

J. Pollack (NASA Ames Research Center)	MARS general-circulation model
J. Posthill (Center for Semiconductor Research)	Analysis of epitaxial diamond films
P. Rice (National Institute of Standards and Technology, Boulder, CO)	Tunneling-stabilized magnetic force microscopy in magnetic garnets
M. Rodwell (U.C., Santa Barbara) S. Allen	Lithography for resonant tunneling diodes; nonlinear transmission lines (devices and circuits); Schottky-collector resonant tunneling diodes
A. A. Sawchuk (USC)	Permutation engine-switching node
L. Schowalter (Rensselaer Polytechnic Institute)	Rutherford back-scattering analysis
G. Stegeman (U. Central Florida)	Third-order nonlinear optical properties of organic materials
W. Steier (USC)	Electro-optic polymers, modulator
R. Stewart (MOEC, GE spin-off co.)	Electro-optic organic salt crystals
A. Stubberud (U. C., Irvine)	Neural nets for control
M. K. Summer (Sangamon State U.)	Knowledge-based software
H. Temkin (Colorado State U.)	Gas source molecular beam epitaxy and semiconductor lasers
O. Tonnesen (Tech. U. of Denmark)	Electro-optic high-voltage sensors
E. Van Stryland (U. Central Florida)	Passive optical limiters; nonlinear optics of phthalocyanines

P.K.C. Wang (UCLA)	Micromachined closed-loop electrostatically actuated reflector (μCLEAR)
H. Wieder (U. C., San Diego)	InGaAs photodetectors
T. Weller (U. of Michigan)	Waveguide circuits
I. Williams (Hong Kong U. of Science and Tech.)	Nonlinear optics of bio-organic crystals
M. Wu (UCLA)	Wavelength division multiplexing
C. Yakymyshyn (ABB)	Electro-optic organic salt crystals
P. Yeh (U.C., Santa Barbara)	Advanced optical processing and neurocomputing
F. Yu (Pennsylvania State U.)	Image processing
S. Zhou (U. C., Santa Barbara)	Photorefractive material and holography

DISTINGUISHED VISITING SCIENTISTS

- Dr. Anne Bagneres, Department of Electrical Engineering, Boston University
- Dr. Floyd B. Humphrey, Department of Electrical, Computer, and Systems Engineering, Boston University
    - IEEE Magnetics Society Achievement Award Laureate
    - Experimental and computational magnetic device and materials physics
- Dr. Junichi Nakamura, Olympus America
    - Active pixel image sensors
- Dr. Venkatesh Narayanamurti, Dean, College of Engineering, University of California at Santa Barbara
    - Ballistic Electron Emission Microscopy
- Prof. Antti V. Raisanen, Senior Research Fellow, National Research Council, Helsinki University of Technology, Espoo, Finland
    - Head, Radio Laboratory
- Dr. Roland Stalder, ETH Zurich
    - Charged Particle Detection
- Dr. James Tillman, University of Washington
    - Microweather Station
- Prof. Pochi Yeh, Department of Electrical Engineering and Computer Engineering, University of California at Santa Barbara
    - Neurocomputing Theory and Nonlinear Science

VISITING INDUSTRIAL FELLOWS

- Dr. Alan Kleinsasser, IBM T. J. Watson Research Center
  - High-temperature superconducting superconductor/normal-metal/superconductor device analysis; high Jc superconductor–insulator–superconductor junction analysis
- Dr. John F. Read, Honeywell Corporation
  - Advanced computing and data storage
- Dr. Yin Shih, Kodak–Datatape, Incorporated
  - Vertical bloch line storage technology
- Dr. Charles Byson, President, Surface Interface, Inc.
  - Charged particle optics; scanning tunneling microscopy
- Dr. John Kovacich, Senior Engineer, Microelectronics Division, Eaton Corp.
  - Tunneling sensor magnetometer for current sensing application

HONORS AND AWARDS

❑ Lew Allen Awards

- Pierre Baldi: In recognition of his scientific contributions to the theory and applications of artificial neural systems.
- Seth Marder: For contributions to the science of organic materials for nonlinear optics and for his efforts to disseminate the results of his work to the community and to motivate and train students in the art of conducting research.

❑ NASA Medals

- H. G. LeDuc: Exceptional Scientific Achievement
- Edward T. Chow: Exceptional Engineering Achievement

- **1993 “R&D 100” Award**

  - Thomas Kenny, William Kaiser, Judi Podosek, and Erika Vote received an “R&D 100” award for the uncooled infrared tunnel sensor, as one of the 100 most technologically significant new products of the year. This award is sponsored by *R & D Magazine*.

CONFERENCES AND WORKSHOPS SPONSORED AND/OR HOSTED BY CSMT

- Fourth Ballistic Electron Emission Microscopy Workshop, Williamsburg, VA, January 25, 1993
- Ballistic Missile Defense Organization Critical Design Review for Clementine Radiation Experiments, January 20, 1993
- Ballistic Missile Defense Organization Technology Applications Workshop, Pasadena, CA, February 2, 1993
- The Second Concurrent Supercomputing Consortium Delta Applications Workshop, Norfolk, VA, March 25–26, 1993
- Fourth International Conference on Space Terahertz Technology—Joint Meeting with University of Michigan, University of California, Los Angeles, CA, March 30–April 1, 1993
- Organic Materials for Nonlinear Optical Applications: Materials Research Society, San Francisco, CA, April 1993
- Ballistic Missile Defense Organization/Innovative Science and Technology Status Review, Colorado Springs, CO, April 28–29, 1993
- 1993 IEEE Workshop on Charge-Coupled Devices and Advanced Image Sensors, Toronto, Canada, June 1993
- American Vacuum Society–Southern California Chapter Workshop on Micromachining: Technology and Applications, Pasadena, CA, July 27, 1993
- American Institute of Aeronautics and Astronautics, Utah State University Conference on Small Satellites, Logan, UT, September 13–16, 1993
- Fall Meeting of the Materials Research Society: Symposium D–"Silicides, Germanides and their Interfaces," Boston, MA, November 1993
- Workshop on Innovative Concepts for Mars Environmental Survey Network Micro-Lander, Arcadia, CA, April 5–6, 1994

LIST OF ACRONYMS

AIRS	Atmospheric Infrared Sounder
ALE	atomic layer epitaxy
ANNIE	Artificial Neural Networks in Engineering (conference)
AOTF	acousto-optic tunable filter
APS	active-pixel sensor
ARPA	Advanced Research Projects Agency
ASIC	application-specific integrated circuit
bbBNN	back-to-back barrier-intrinsic n-type devices
BEEM	ballistic electron emission microscopy
BMDO	Ballistic Missile Defense Organization
CAIBE	chemical-assisted ion etching
CCD	charge-coupled device
CHFET	complementary heterojunction field-effect transistors
CMOS	complementary metal-oxide semiconductors
CSCC	Concurrent Supercomputing Consortium
CSMT	Center for Space Microelectronics
CSO	Caltech Submillimeter Observatory
DAST	JPL inorganic crystal
DCC	Data Compression Conference
DOD	Department of Defense (U.S.)
DOE	Department of Energy (U.S.)
DRA	Defense Research Agency (British)

EM	electromagnetic
FE-IE	finite element–integral equation
FPA	focal plane array
GOMAC	Government Microcircuit Applications Conference
HBL	horizontal bloch line
HEMT	high-electron-mobility transistor
HESI	high-energy solar-imaging satellite
HESP	high-energy solar-physics satellite
HIP	heterojunction internal photoemission
HPCC	high-performance computing and communication
HTS	high-temperature superconductor
HTSSE-II	High-Temperature Superconductor Space Experiment–Phase II
HyLite	Hypermedia library technology
IEEE	Institute of Electrical and Electronic Engineers
INSTEP	In Space Technology Experiments Program
ISEC	International Superconductive Electronics Conference
ISO	International Standards Organization
KAO	Kuyper Airborne Observatory
LeRC	Lewis Research Center (NASA)
LIDAR	light detection and ranging
LIGA	German acronym for a combination of deep-etch x-ray lithography, electroplating, and injection molding
MAPS	Microwave-Powered Aircraft Platform System
MBE	molecular beam epitaxy

MESUR	Mars Environmental Survey
MM&D	micrometeorites and debris
MMIC	millimeter microwave integrated circuit
MOCVD	metallorganic chemical vapor-deposition reactor
MOSFET	metal-oxide semiconductor field-effect transistor
MRS	Materials Research Society
NAWC	Naval Air Warfare Center
NEP	noise-equivalent power
NIPS	Neural Information Processing Systems (conference)
NRL	Naval Research Laboratory
NTF	National Test Facility
OEIC	optoelectronic integrated circuits
PDE	partial differential equation
PMMA	polymethylmethacrylate
QUID	quartz upside-down integrated device
QWIP	quantum well infrared photodetectors
RADMON	radiation monitor
RAP	resource allocation processor
RRELAX	Radiation and Reliability Assurance Experiment (on Clementine)
RTD	resonant-tunneling diode
SAR	synthetic aperture radar
SCRTD	Schottky-collector resonant-tunneling diodes
SDI	Strategic Defense Initiative

SEE	space environmental effects
SEU	single-event upset
SIS	superconducting–insulator–superconducting
SMIM/FIRST	Submillimeter Intermediate Mission/ Far Infrared Space Telescope
SNS	superconductor/normal metal/superconductor
SOS	silicon-on-sapphire substrates
SRAM	static random access memory
STIG	Space Technology Interdependency Group
STRV	Space Technology Research Vehicle
STTR	Small Business Technology Transfer Program
TCA	Technology Cooperative Agreements
TCP/IP	transmission control protocol/ Internet protocol
TEM	transmission electron microscopy
TTM	tunneling transmission microscopy
VBL	vertical bloch line
VLSI	very-large-scale integration
YBCO	$YBa_2Cu_3O_{7-x}$
YIG	yttrium-iron-garnet
YSZ	yttria-stabilized zirconia
μCLEAR	micromachined closed-loop electrostatically actuated reflector